
ASSESSMENT OF ELECTRO-MECHANICAL COMPONENTS OF BAKOLORI SMALL HYDROPOWER PLANT FOR REFURBISHMENT AND
MODERNIZATION

By

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ABSTRACT

This paper presents a technical study of Bakolori small hydropower plant for possibility of upgrading of the electro-mechanical components. Physical inspection of the plant was carried out and commissioning and operation records were obtained and analyzed. The 3.2 MW Bakolori small hydropower plant was commissioned in 1978 but has been out of operation since 1989 after a decade of continuous operation. The self-priming pumping unit installed to evacuate leakage water from the turbine's carbon seal of the coupler was damaged and allowed water seepage to mix with oil in the turbine resulting in plant shut down. Our findings show that the plant can be retrofitted with new equipment having improved efficiency and increased capacity for higher energy output.

Keywords: pumping unit, leakage, turbine, seepage, shutdown, retrofitted, efficiency, energy output

INTRODUCTION

Bakolori Dam in Sokoto state, Northwest of Nigeria was completed in 1978 and its reservoir filled by 1981. It is a major reservoir on the Sokoto River, a tributary of the Rima River. The dam has a capacity of 450 million cubic meters, with a reservoir covering 8,000 hectares extending 19 km upstream (Abdullahi et al., 2014). The dam is under the management of Sokoto-Rima River Basin Development Authority.

In 1978, two vertical-axes shaft Kaplan turbines of 1600 kW each (total output of 3.2 MW) were installed at the dam and put in operation for power generation. The plant provided electricity supply to the immediate community for a while and for irrigation but, the plant was shut down after a decade of operation. Small hydropower plants are confronted with a variety of operation and maintenance challenges. These problems may include frequent choking of strainers, choking and

puncturing of cooler tubes, damage to cooling water pumps, frequent failure of shaft seal, damage to drainage or dewatering pumps, valves, piping, intake seals, intake gates and damage to dam structures among others. Due to long gestation period and large capital investment required for construction of new dams, possibility of upgrading of old electromechanical units by refurbishment, renovation or modernization is considered to be most cost effective means for capacity addition in short span of time (Mo et al, 2001, AHEC/MNRE, 2012). The refurbishment of facilities in a hydropower dam may result in the achievement of multiple effects such as:

- i. increase static and dynamic reliability
- ii. increase service life of units
- iii. reduce production costs
- iv. increase generation of electricity
- v. increase plant efficiency

TECHNICAL PRESUPPOSITIONS FOR REFURBISHMENT

Refurbishing a low head plant such as small hydro investments may be capital intensive. Furthermore, low heads plants highly suffer from scale effects, mainly because, if compared to a high head plant with the same output, they have a greater incidence of civil works cost.

In planning to refurbish any plant, it is necessary to rank different project alternatives, included the zero

$$NPV = \sum_{i=1}^n \frac{[R_i - (I_i + O_i + M_i)]}{(l+r)^i} + V_r + E_v \tag{1}$$

l = lifetime period (years)

I_i = investment in period i

R_i = revenues in period i

O_i = operating costs in period i

M_i = maintenance costs in period i

V_r = residual value of the investment over its lifetime

E_v = environmental added value of the plant due to the refurbishment

r = periodic discount rate (%)

n = number of lifetime periods

Also,

$$R_i = P_i \times E_i = P_i \times \eta_i \times \gamma \times H_i \times Q_i \times T_i \tag{2}$$

P_i = price of the energy produced in period i (unit cost/kWh)

E_i = energy produced in period i (kWh/time)

η_i = overall efficiency of the plant in period i (%)

γ = unit weight of water (kN/m³)

H_i = net head in period i (m)

Q_i = flow rate in period i (m³/s)

T_i = hours of operation in period i (h)

Equations (1) and (2) then gives:

$$NPV = \sum_{i=1}^n \frac{[P_i \times \eta_i \times \gamma \times H_i \times Q_i \times T_i - (I_i + O_i + M_i)]}{(l+r)^i} + V_r + E_v \tag{3}$$

Each factor of this formula represents a field of action in the context of a refurbishment, exception made in general, for the financial parameter r and the energy price P_i . Environmental added value cannot be reduced to a purely monetary value. In this context there

alternatives (i.e. that is no refurbishment at all). The best approach will be by using Net Present Value (NPV) method (ESHA, 2004):

is only the need of taking into account, in the following considerations, the fact that, during the refurbishment, different alternatives can have different environmental consequences, both in terms of purely monetary costs and even of environmental benefits (ESHA, 2004).

Experience of running hydropower station reveals that even after detailed project planning and quality control measures taken at various stages from inception to commissioning, several unforeseen problems do take place during the operation and maintenance resulting in forced outages, low generation and load shedding. Some of the reasons which can be attributed to these undesired phenomenon are that the hydropower station equipment are custom-built in construction and tailor made at each area of application and design, manufacturing, erection, commissioning, operation and maintenance and equipment cannot be fully assembled or tested at works (AHEC, 2012).

Maintenance exercise at predetermined time interval is therefore, planned in order to achieve the following:

- i. Quality and reliable operation of equipment on long term basis through identified periodic inspection and checking of components and subsequent replacement of parts, wherever required.
- ii. Maximum availability of equipment with least number of shut downs by ensuring that the rate of deterioration of any component does not exceed the life expectancy of the equipment at any stage.
- iii. Eradication of operational problems by timely analysis of the cause of faults or problems and replacement of short term solutions by long lasting and permanent ones.

METHODOLOGY

Bakolori Small Hydropower Plant is under the management of Sokoto-Rima Basin Development Authority. In order to carry out a comprehensive assessment of the existing condition of the plant, data from technical documentation, testing and commissioning records and information on operational history of the plant were sought from experience staff members at the dam sites. Furthermore, visual

inspection was performed on major components of interest in the plants. Such components include: turbine guide bearings, shaft, guide apparatus, governors, thrust bearings, rotors, bottom brackets, top brackets, stators, ventilation ducts, baffle plates, braking and jacking systems, main inlet valves, bye pass valves, drain valves, cooling water systems, draft tubes, draft tube gates, air compressors, drainage and dewatering system, transformers, relay and control panel and switchyard structures.

All units and station auxiliaries were also inspected and checked for existing conditions. Further studies were carried out on the operation parameters, history of machines over years of running, major events, repair works done in the past and repeated problems encountered during plant operation to assist in determining components and equipment to be refurbished, modernized or replaced.

Refurbishment

Refurbishment involves the selective replacement of critical components such as turbine runner, generator winding with class 'F' insulation, excitation system, governor etc.

Refurbishment of worn out parts can lead to increase efficiency and reliability of plant operations and also improve peak power and overall energy output (AHEC/MNRE, 2012).

The analysis of the future risk of failure can be helpful in setting some priorities of actions. Even if there is no particular necessity, refurbishing can be an opportunity to increase the overall efficiency and the energy production of the plant. To refurbish a plant, a priority scale on which parts of the plant are to be upgraded should be defined on a technical and economic basis.

Modernization

Modernization is a continuous process and can be part of refurbishment and renovation activities. The reliability of plant can be further improved by using modern equipment like static excitation system, microprocessor based control, electronic governor, high speed static relays, data logger, vibration monitoring and silt content analyzer (AHEG/MNRE, 2012). Replacing old hydro turbines with modern ones is feasible if civil structures are found healthy enough to accommodate the new changes that will occur.

Optimization of Choices

In hydro machines, particularly of old design, there are generally enough safety and over load margins which can be usefully exploited to get about 10 – 15% additional capacity. Sometimes by replacing generator, runner and some other parts, by better design of manufactured components and by retaining under water embedded parts; additional capacity up to 50% can be achieved (Aggarval; ESHA, 2004).

In old machines, stator and rotor winding is of class B insulation having higher thickness than present day class F insulation. So if this class B insulation is replaced with class F insulation, the copper area of conductor in the existing slots can be increased by about 30%. This increases the capacity of stator and rotor. If the capacity of other component parts such as shaft is adequate, then the unit can be upgraded by about 20-30% (Impresit Progetto manual).

DISCUSSION OF FINDINGS

In 1978, two vertical-axes shaft Kaplan turbines of 1600 kW each (total output of 3.2 MW) were installed and put in operation until a major breakdown was reported in 1989 when the plant was shut down after 11 years of continuous operation. Some basic features of

the hydropower plant are shown in Figure 1 (photographs taken at the site of Bakolori plant).



(a)



(b)



(c)



(d)

Figure 1: (a) Kaplan turbines (b) Wheel gate pump station (c) Hydraulic station (d) Tailrace

- i. **Operating condition:** Net Head (18 m), Discharge ($9.8 \text{ m}^3/\text{s}$), Efficiency (92.5 %)
- ii. **Speed:** The rated speed of the turbine is 428 rpm. The full runaway speed of the turbine when operation under maximum net head, with distributor vanes fully open and generator disconnected is 1300 rpm.
- iii. **Runners:** Adjustable Kaplan, 13 % Chromium, 4 % Nickel stainless steel type with the required control and auxiliary equipment. The design

- shaft.
- iv. **Shaft:** The turbine shaft is of forged carbon steel properly heat treated and capable of withstanding the heaviest operating conditions, including generator short-circuiting. The critical speed of the rotating parts is less than 130 % of the runaway speed. The shaft is of hollow type to accommodate the blade actuating devices and provided with a servomotor located in the upper part. The cylinder of the servomotor is forged steel and

the piston is made of high strength cast iron. A pressure gauge is provided with shut-off valve and connecting line to enable oil pressure in the servomotor to be read. A suitable seal box is provided for the hydraulic sealing of the shaft, complete with interchangeable carbon sector rings and seal-adjusting devices.

- v. **Distributor and Wicket gates:** The stay ring consist of welded steel structure, designed to support and transmit to the lower parts the weight of the upper portion of the turbine and generator runner. The stay ring is complete with stay vanes, support plates and bolts for the annular anchoring into the surrounding concrete. The wicket gates are of chromium-nickel stainless cast steel and they are provided with lubricating bronze bushings for the lower and upper pivots. The wicket gate mechanism is designed to transmit the maximum stresses imposed by any regulating conditions. The gate controlling servomotor is open by oil pressure and close by weight action. A gravity-type shut-off device is provided to ensure the closing of wicket gates under normal and emergency conditions.
- vi. **Cone and Elbow Draft Tube:** The cone and elbow draft tube are lined with welded steel plate. Reinforcement and anchors are provided for securing the liner to the concrete. The liner is fitted with flanges for bolting to the stay ring and provision is made between lining and concrete for draining seepage losses to the powerhouse pit through a pipe.
- vii. **Governors:** The two turbine governors are of the oil-pressure type, with an actuator that receives signals from the permanent magnet generator installed on the shaft of the main generator. Each governor consist of a welded steel plate oil reservoir, with level indicator and oil-filling filter, a vertical pumping unit for generating the required oil pressure for turbine control, an emergency reciprocating pump, manually operated, for the unit start-up in the event of a failure on both a.c. and d.c. supply circuits. A main distribution valve for wicket gate control, a runner blade control valve, inner water cooler for the governor oil tank and a separate wicket gate control unit with oil-actuated servomotor supply for pumping units.
- viii. **Drainage Pumps:** Self-priming pumping unit to evacuate leakage water from the turbine carbon seal, including normal service pump 230/400V a.c. motor driven, for intermittent operation controlled by a float-type switch located in the turbine sump and a reserve pump, 110V d.c. motor driven, to be automatically switched on when the normal pump fails to operate.
- ix. **Generators:** The generators are of rating 1.765 KVA directly coupled to the Kaplan turbines. They are of synchronous, 3-phase, vertical shaft type, with salient massive poles, short coil pitch, diamond-type windings. The lower generator guide bearing is of the self-lubricating type and the shaft is hollow with coupling flange for connection to the turbine shaft. Basic characteristics of the generator include: capacity (1.765 KVA), frequency (50 Hz), speed (428 rpm), voltage (6000 V), runaway speed (1250 rpm), power factor (0.85), number of poles (6), excitation power (17 kW), efficiency (95.2 %).
- x. **Exciter:** The generator exciter is of the static type, supplied from the current and potential transformers connected to the generator bus

in order to provide compound vector values. The exciter is capable of supplying, on a continuous basis, 140% of the power required at rated generator output.

- xii.* **Automatic Voltage Regulator (AVR):** The automatic voltage regulator associated to the exciter is of the static type and capable of maintaining the generator terminal voltage at a preset value, ranging from 90% to 110% of rated value at no-load and from 95% to 105% of rated value at full load.
- xiii.* **Generator Braking System:** The generator braking system is of mechanical type, operated by compressed air and has sufficient capacity to bring the unit to standstill within five minutes from closing of the turbine wicket gates with unit running at rated speed.
- xiiii.* **Control Panels:** Control switches, protective relays and indicators mounted on the front panel of each actuator cabinet and panel

boards provided the following operations: starting of cooling circuits, oil pump starting, unlocking of turbine governor, opening and closing of valves, speed control, opening of wicket gates etc.

- xiv.* **Substation:** The outdoor substation consist of two 3-phase, 2000 kVA, 6000/33000 V step-up transformers.

The main reason why one of the turbines was shut down is that that the self-priming pumping unit installed to evacuate leakage water from the turbine carbon seal of the coupler was damaged and allowed water seepages to mix with the oil of the turbine. This incidence caused severe damage to the turbine components over time as a result of rusting and corrosion of parts as shown in Figure 2.



(a)



(b)

Figure 2: (a) leakage at the wicket gate (b) leakage at the pump house

The two 1.765 KVA, 3-Phase, synchronous generators coupled directly to the Kaplan turbines are in good working state and the static exciters examined are

also in good conditions. Although the concrete structures at the dam site are still solid, serious leakage

of water at the wicket gates was observed. This is due to bad seals and minor cracks at welded joints.

The hydraulic system for control of opening and closing of gates need upgrading and one of the two hollow jet valves is not functioning as a result of bad shaft. Switchyard equipment such as circuit breakers, isolators and the two power transformers are in good working condition partly because they have not been put to serious use since installation.

Replacing an old Kaplan turbine with another new one may not be an easy task. Even though the plant parameters may be the same, it is not unusual that the new unit can be different from the old one in many aspects, such as:

- (i). rated speed (higher speeds are now common)
- (ii). blades number
- (iii). runner diameter
- (iv). draft tube shape
- (v). runner centerline elevation

All these aspects require some adaptation of the new unit to the existing structures, both mechanical and civil. The service life of a turbine in continuous operation is between 30-35 years if adequate and appropriate operation and maintenance procedures are put in place. The nature of the damage experienced by the Kaplan turbine inspected coupled with the fact that new technologies have emerged over the years, it is recommended that:

- (i). The turbines should undergo major replacement of component parts and renovation but if the cost of this procedure is very high, outright replacement of the turbines with modern, high performance, slightly higher rated turbines of similar configuration should be carried out.
- (ii). Water leakage at the wicket gates and other sections should be tackled by replacing worn out seals, weak weldment should be corrected

and gate frames, gate bonnets and other structural members should be strengthened.

- (iii). The hydraulic system for gates operation and the bad hollow jet valve should be serviced while high grade hydraulic oil should be provided for effective operation.

CONCLUSION

Although hydropower is a proven and well-advanced technology, there is still room for further improvement through optimization of operation and more robust and cost effective technological solutions. Older turbines can have lower efficiency by design or reduced efficiency due to corrosion and cavitation damage. Potential therefore exists to increase energy output by retrofitting with new equipment having improved efficiency and increased capacity.

It is not unusual that the gross head is decreased because of material sedimentation downstream of the powerhouse or in the tailrace channel. Restoration of the gross head can be achieved by dredging the tailrace channel or the river.

The most common way to refurbish a plant is to replace the turbine. In principle it is a simple task for any kind of small hydroelectric plant, but in case of low head plants the options are not many. New units generally have different shapes and dimensions from old ones, so to replace an old unit with a new one, it is necessary to evaluate also the possibility of removing embedded parts of the unit.

There is also the need to wait for dismantling the old unit, check the real geometry, adjust very precisely the coupling surfaces; all this process can take a lot of time and prolong the unit outage with the consequent loss of production. Furthermore, any interaction with civil works is potentially a source of risk, especially in case of old buildings whose actual conditions are very often not completely known.

Contingencies must be expected, affecting both time and costs of refurbishment.

REFERENCES

Abdullahi S. A., Muhammad M. M., Adeogun B. K., I. U. Mohammed (2014). *Assessment of Water Availability in the Sokoto Rima River Basin*, Resources and Environment, Vol. 4 No. 5, pp. 220-233

Aggarwal R.K. Refurbishment, Modernization and Upgrading of Hydro Plants. Retrieved on 2nd July, 2016 and available at <https://www.scribd.com/document/270232326/Refurbishment-Hydro-Plants-Rk-Agga-Rwal>

AHEC/MNRE (2012). *Guidelines for Modernization, Renovation and Upgrading of SHP*. Alternate Hydro Energy Centre Indian Institute of Technology, Roorkee, India

AHEC (2012). *Guidelines for Operation and Maintenance of Small Hydropower Station*, Technical

Publication, Alternate Hydro Energy Centre Indian Institute of Technology, Roorkee, India.

Clifford Power, Accessed online on 2nd July, 2016 and available at: http://www.cliffordpower.com/stuff/content_mgr/files/0/d941ffb19de68c8d4925afa005635e7b/misc/is_55_alternator_temp_rise_vl.pdf

ESHA (2004). *Guide on How to Develop a Small Hydropower Plant*. Retrieved on 1st July, 2016 and available at www.esha.be

Impresit, Progetto Preliminare; General Specifications, Bakolori Project, Milan, Rome

Mo B., Solvang E., Heggset J., Nordgård D.E., Haugstad A. (2001). *Integrated Tool for Maintenance and Refurbishment Planning of Hydropower Plants*, SINTEF Energy Research, Norway

ESHA (2012). *Small Hydropower Plant for Developing Countries*. Retrieved on 6th July and available at www.esha.be